U.S. Department
of Transportation
**Federal Aviation
Administration**

800 IndependenceAve SW
Washington DC 20591

MAY 27 2003

Dr. Ing. Giok Djien Go
Pfahlgraben. 45
D-65510 Idstein
Germany

Dear Dr. Ing. Giok Dijien Go:

This is in reply to your letter of March 27 in which you expressed concern over the possibility of emergency exits in a passenger aircraft becoming unavailable for passenger egress as a result of events in a crash landing.

The Federal Aviation Administration (FAA) and the aviation industry have been aware for some time of various means for assuring the opening and accessibility of emergency exits following a survivable crash landing. An exit might be rendered unusable for a number of reasons, including fuel fire inside or outside the cabin, structural jamming, obstruction by disoriented or incapacitated persons, escape slide damage, or other causes. Numerous concepts for assuring the accessibility of exits have been suggested to the FAA in the past. Several years ago the FAA was involved in the evaluation of a unique experimental stored-energy, or explosive, exit-opening system that could create an opening in the cabin wall in the event the exit became unusable because of structural damage. The possibility of inadvertent actuation of such a system, however, raised major safety concerns.

Your letter does not specifically request funding for a proposal. It does, however, mention the matter of your patented systems. We would like to point out that the FAA does not fund the proof-of-concept development of aircraft designs involving basic concepts that are common knowledge throughout the industry. Such development is more appropriately carried out by competitive private enterprise, taking into consideration the important non-safety characteristics and trade-offs between performance, design details, cost, maintainability, and other factors that ultimately determine the configuration, efficacy, and marketability of the system.

If you wish to consider further development of your ideas, the FAA is most willing to provide advice and guidance regarding airworthiness certification of equipment for use in civil aircraft. Please contact the Brussels Aircraft Certification Staff of the FAA, as follows:

Thomas A. Boudreau, Manager
Brussels Aircraft Certification Staff
27, Boulevard du Regent
B-1000 Brussels Belgium

Telephone 011.32.2.508.2710
Fax 011.32.2.230.6899

Thank you for your interest and effort in improving aviation safety.

Sincerely,

Susan K M Cabler
FOR David Hempe
Aircraft Engineering Division

Neck Injuries in Car Accidents - Causes, Problems and Solutions

Klaus Langwieder; Wolfram Hell

Verband der Schadenversicherer e. V. -VdS-

CSD = Cervical Spine Distorsion = HWS-Verletzung

Neck injuries are the second frequent injury cause in car accidents with personal injuries. In many countries they have gained epidemiological importance and they are still increasing in importance. This is due not only to technical but also to social reasons and problems of medical diagnosis.

Available incidence statistics show definite variation depending on insurance system, car population and social behaviour.
In the US from 3.8 million rear-end impacts approximately 20 % of the car occupants complain symptoms from their neck [1]. From this data the annual incidence is reported 3.8 per 1,000 population. For the entire Swiss population the annual incidence is only 0.44 per 1,000 [2], whereas Norwegian figures arrive at 2 per 1,000. Australian and New Zealand statistics report 1 per 1,000 as well as first estimations for Germany. In Canada in the province of Quebec an incidence of 7 per 1,000 was reported, whereas in Saskatchewan the rate was ten times higher with 70 per 1,000 [3]. As possible explanation for the significant difference of these Canadian provinces, the no fault insurance system in Quebec versus the tort system in Saskatchewan was assumed.

An estimation of social and economical costs for cervical distorsion injury (after the injury cost scale) [4] arrives at 28,000 DM as average cost per medium CSD (AIS 1) injury. At this basis the total estimated annual socio-economical costs for rear-end collisions in Germany would amount to around 2 Billion Marks, that means 1100 MECU.
Estimations in other countries were for The Netherlands 150 MECU, for Sweden 210 MECU and for Canada (only for British Columbia) 450 MECU.
A Swedish research group [5] very roughly calculated about 5-10 Billion ECU for the whole European Union.
US estimations (IIHS) were 10 billion $ per year [6].

Based on the Accident Research Material from the German Motor insurers of 15.000 car to car crashes [7] with injured occupants from the year 1990 characteristics of neck injuries could be analyzed.
The data material represents about 16 % of all car to car crashes with personal injury of the old federal states in Germany.
It was found that in 81 % of the accidents at least one of the occupants involved complained a cervical spine distorsion injury. These reported injuries were classified according to the Abbreviated Injury Scale as minor AIS 1 (= acute strain with no

fracture or dislocation). 80-90% of these injuries showed a complete heeling in short time, at longest after 2-3 weeks. But some long-term casualties which may last for years, have been reported, too. In comparison to previous accident investigations the incidence of cervical spine distorsion in Germany has almost doubled during the last 20 years [8/9], (Fig. 1).

Neck Injuries and Collision Type

By analyzing the overall injury distribution of the front car occupants, injuries to the cervical spine are standing at the second highest frequency after head injuries. By looking at severe injuries (rated AIS 3+ Abbreviated Injury Scale), cervical spine injuries were found after injuries to HEAD, LEG, THORAX and ABDOMEN at the fifth position (Fig. 2).

Looking at the car to car accident configuration a clear dominance of REAR-END collisions with 61 % (hyperextension injury mechanism) could be seen. SIDE-COLLISIONS (lateral bending) were noticed in 28 % whereas FRONTAL collisions (hyperflexion) could be observed only with 11 % in the material [7]. S. 49 Bild 52.

Head Risks - low technical standards and public awareness of this safety system

Because of the high frequency, rear-end accidents have been analyzed more deeply. Here the head-rest plays an important role for the prevention of hyperextension injuries.

The typical present situation in many cars (especially for tall passengers) is demonstrated in Fig. 3.

These headrests fulfil the European construction standard ECE R17 [8] for head-rests, which is about 20 years old. A seating test confirmed that tall persons could not be protected with the headrests of many cars. Although safety engineers know that the ECE R 17 norm is insufficient, the head-rest for a long time was the "forgotten safety feature" because no significant improvements could be observed. By looking at car advertisements and publications in technical journals about seat construction a lot of "wrong" head-rest positions could be observed [9]. Many car manufacturers pay more attention to cost limitation of head-rests instead of sufficient height-adjustment and horizontal distance.

In addition field studies demonstrated that up to 70 % of the occupants showed a too low height adjustment [8] (Fig. 4). This means that from the car passengers there is also no awareness of the problem. Again it is to complain that in about one third of the head-rests the adjustability has been not enough related to the height of the occupants. The "Gold standard" for optimal height adjustment is reached from only 18 % of the current cars fulfilling the recommendation that the upper edge of the head-rest should end with the upper edge of the head. Furthermore in inquiries it turned out that not only the possibilities of height adjustment of the head-rests are very uncomfortable, but also the stability and fixation of the head-rests has not been sufficient.

Influence of Technical Parameters

For a deeper investigation of rear-end collisions many different variables have to be realized which influence the possibility of CSD-injury. The most important parameters are:

The head-rest influences the hyperextension with its form, height, horizontal distance and damping characteristics of the padding material.

The seat-back stiffness and geometry has the same importance than the head-rest because the elasticity of the seat influences the rebound who is associated with high energy turnover and possibly injury causation [10].

The loadings to the Cars are differing significantly related to the car masses involved. For example, if a luxury target car with 2000 kg hits a 700 kg compact car, the delta v for the occupant of the compact car is nearly 3-times higher than in the luxury car.

Also the stiffness of crash absorbing zones and the different models (i.e. hatchback in comparison to station wagon) are of major importance, which has been clearly demonstrated by statistics and crash tests [7, 10].

Important accident parameters were velocity, collision angle and degree of overlap, the fact of pre-impact breaking and awareness of the coming accident.

Neck Injuries and Insurance Problems

The broad spectrum of car damage degree and reported cervical spine injury demonstrates the case example (Fig. 5). This accident undoubtedly has had a very low Energy Equivalent speed but the driver complained a long history of subsequent disease with an intended job inability, which was refused in the last medical expertise.

Figure 6 in contrary shows a very severe rear-end impact with an Energy Equivalent speed of about 40 km/h in which the driver sustained no injury. The photo shows a high height-adjustment of the head-rest and if the driver had a relatively low horizontal distance the injury risk substantially has been reduced.

The problems of the insurance companies and the claimant are influenced by the quality of the medical diagnosis. Only 7 % of the diagnoses were made by specialists as orthopaedics and surgeons. Most of the diagnoses have been made in the Emergency room or came from General Practitioners or Internists.

About 90 % of the claimants have been compensated for pain and suffering although the diagnosis was based in 30 % just to one symptom where in most cases only neck-pain is registered (Fig. 7).

Medical Problems with Neck Injuries

Generally increased injury risks could be observed for taller, older and preferably female persons.

Current radiologic techniques (X-ray, MRI) are unfortunately not able to show objective criterias for minor and medium CSD injuries.

The therapy of CSD is very heterogeneous. Only one kind of therapy was ordered mostly, mainly pharmaceuticals or neck collars. It seems remarkable that one fourth of the neck collars have been worn longer than three weeks. No positive effect from neck collars was found in a big survey carried out in Canada [11], but even uninjured individuals wearing a neck collar longer than two days can show objective muscular symptoms of CSD.

In future medical improvements have to be made with:

- o homogeneous definition and interpretation of CSD and
- o standardized primary diagnostics (important improvement for insurance claims would result from a specialized CS-form)
- o more objectivity in CS-diagnostics
- o refined concepts for therapy and
- o more research activity

Facts from Real-Life Crashes as Background of Sled-Tests

Concerning the Crash Severity, an in-depth Analysis of 496 Cases [12] showed that low delta v crashes (69% up to 15 km/h) dominate (Fig. 8).
In a rough estimation the possibility of simulated injuries was analysed the criteria of which should be low delta v in combination with very poor medical documentation. About 20 % of the very low and 29 % of the low delta v crashes, that means about 50 % of the reported cervical spine injuries, could possibly be simulated or didnot fulfil valid medical criterias.

To evaluate the influence of the car model for the risk of neck injuries approximately 50 cars from the data set "Vehicle Safety 90" from the German Motor insurers were statistically investigated. From this data a "Neck Injury Factor" (NIF) for the considered cars was defined. The NIF describes the frequency of neck-injury-claims for a car regarding the registration frequency of this car on the road.

The neck injury risk to low weight cars arrives at a 4-5fold value as in cars of 1,400 kg and up (Fig. 9). Thus, the smaller the car, the more attendance has to be given to optimum seat/head-rest design. But the NIF is not only a function of the car mass. Due to improper design of the head-rest the relative risk of injury within one car mass category can double.

The statistical results for the NIF were in general comparable to a Swedish investigation [10] with a correlation coefficient of 0.77, although two different statistical methods have been used (Fig. 10).

Ramping

Results from Sled-Tests with Volunteers

To isolate the influence of the car seat as important design factor and to analyse the possibilities of comparison of real accidents with tests a series of 34 sled tests with volunteers at a speed of 8-11 kph arriving at 2,5g has been made (Fig. 11). 1/3 of the checked real-life accidents, car seats had to be rated as "dangerous" in pre-tests, so that no volunteer tests with these seats could be dared. Therefore, only 9 different seat/head-rest types have been tested. The tests have been below the injury level. But in one case, a volunteer suffered a minor CSD and had neck-pain for about two days. Some volunteers had smaller complaints lasting for 1-2 days without CSD.
As a main result it was confirmed that most of the common seat/head-rest constructions in all car categories are not sufficient. All observations of neck loadings and head/neck movements strongly correlated with the horizontal distance, which turned out to be the most important factor in injury causation.

After full contact with the seat back (40 ms) the torso is accelerated (Fig. 12) while the head remains in its initial position. Significant head acceleration starts after 100 ms. This delay of head and torso acceleration results in a relative motion between head and torso. From the high speed video analysis, it could be observed, that head - head restraint contact occurs at approx.130 ms. This means that the forces and moments causing the head acceleration (up to 4g before contact) and head rotation have to be exerted by the neck. The maximum head acceleration is reached after head/head-restraint contact. Elasticity of the seat leads to a rebound after approx. 200 ms.
Due to a ramping effect in the initial phase, a correct position of a headrest requires a height adjustment where the upper end of the head-rest should correspond to the upper end of the head.
The picture on the left side shows a good performing Porsche 911 seat with a low grade of head extension in comparison to a poor rated seat from an Opel Corsa A (model '85) with a high grade of head extension.

Volunteers with some neck pain (smaller complaints for 1-2 days) and the one volunteer with CSD injury showed highest values for horizontal distance and high peak values for angular displacement between head and torso maximum (Fig. 13).
Some results from our sled tests indicate, that the maximum angle of the Hyperextension could not be used as an injury criteria, because the physiological hyperextension limit was not reached although neck complaints were reported. More relevant could be the angle velocity and angle acceleration of the head, which could be calculated in the sled tests only with mathematical inaccuracy, but it could be found out that all complaints (injuries) in the test-series correlated with a maximum angle acceleration > 500 rad/s^2. This peak of angle acceleration always occurred in the turn around phase of max. extension to flexion. Also relevant was the angle velocity, where neck complaints appear after 10 rad/s.
These first criteria could be useful for the seat constructor. For the technical expert, who has to reconstruct the accident and has to evaluate the plausibility of a whiplash the delta v correlation could be of importance. But the sled-test results indicate a significant influence to the delta v correlation exerted by the horizontal and vertical head-headrest distance. Here following proposal could be discussed:

No injury could be assessed at

delta v < 5 kph at poor headrest geometry
delta v < 10 kph at average headrest geometry
delta v < 15 kph at well designed headrest geometry.

Comparison of Sled Tests with Risk in Real-Life Crashes

A ranking of the tested seats was evaluated by a "point system" measured on various body factors, which should describe the quality of the head restraint:

- o height
- o horizontal distance
- o shape (size, curvature)
- o padding (hard-soft)
- o kinematics of the volunteers (angular displacements, accelerations)
- o characteristics of the seat back (elasticity, stiffness)

Good but not optimal results shows the PORSCHE 911 seat with integrated headrest with 76 % of the theoretical maximum. BMW 5 and Mercedes E-class seats performed well both with 64 %, improvements could be made with a lower seat elasticity and better geometry. The frame-headrest from the Audi 80 performs also well, although it allows different impact conditions, because some volunteers hit the outer frame, others the center of the headrest. Therefore a solid headrest appears as the better solution.
VW Golf III (93) and Mazda 323 will need more improvements with geometry (horizontal and vertical) as well as a change of the unsolid fixation of the height adjustment.
Ford Escort, VW Golf II and Opel Corsa A (85) showed clear deficits as well as in headrest geometry as in seatback construction.

Seats with an estimated injury risk for the volunteer were: Fiat Uno, Nissan Micra, Peugeot 205 and Renault 5. These (poor) seats/headrests could therefore not been tested.

To get an impression of the headrest constructions of the todays cars ('96 models) TU Graz used a sophisticated H-point dummy with the simulation of the 95% and 50percentile male. Here for 105 new cars, partly listed in Fig. 14, the horizontal and vertical gap of the seat-headrest was documented and evaluated [13]. Only for 19 cars the headrest construction was rated good (i.e. Volvo 850, Opel Corsa B, Mercedes E-class, Fiat Punto cabriolet). 54 cars were rated acceptable (i.e. BMW 5, Fiat Punto) and 31 were rated unacceptable (i.e. BMW 3, VW Passat, Lancia Delta).

Findings from real accidents and sled tests with volunteers show comparable results (Fig. 15). Cars, of which the seats/headrests got a negative assessment in sled tests show higher risks in real accidents; good test results got confirmed by lower accidental occurrence. Only 2 cars show some differences, which can be explained by a possibly higher real life injury risk of the frame headrest concept (Audi 80) and a better reflexion of the car mass by the NIF (Opel Corsa A).

Summary of Findings and Requirements

Thus from improved seat/headrest design a significant reduction of neck injuries up to 50 % is to be expected. For an optimal positioning automatic adjustment of the height of the head-rest i.e. related to the longitudinal position of the car seat or by special measurement of the head position should be integrated in future cars as standard equipment. As low cost solution fixed or integrated headrests, which cover the 95% man are an alternative. As a minimum requirement the range of possible height adjustment has to be extended.
One other very important issue is the reduction of the horizontal distance of head/headrest either statically or with smart "active" systems (i.e. Saab Delphi)
Furthermore stiffness and elasticity of the seat frame, padding of the seat (higher damping rate) and ergonomics are to be optimized.

There is an urgent need for updated European Construction Standards for head-rests with an improved height and horizontal distance. The ECE R 17 has to be revised as soon as possible.

In future European car-crash-standard~~s~~ requirements of neck injury protection and seat/headrest behaviour should be integrated. Especially the dummies used should be equipped with appropriate systems for neck load measurements.

To this aim biomeachanical tolerance values for neck injury risk have to be analyzed with highest priority because CSD tolerance limits are currently not clearly defined.

In the sled tests not the maximum angle of hyperextension, but the angle velocity and the angle acceleration of the head proved to be relevant criteria of neck injury risk. All complaints correlated with a maximum angle acceleration > 500 rad/sý and an angle velocity exceeding 10 rad/sec.
For well designed headrests no neck injuries are to be expected below a delta v of 15 kph, but this may be not true for some poor design concepts of headrests still on the market today.
These first findings including real accidents and sled tests with volunteers have to be critically compared and discussed with other available biomechanical results.

The development of a realistic dummy neck and of tolerance values as well as dynamic test standards for seat/headrest performance is the most important aim for the future.

rotating velocity

rotating acceleration

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Figure 1: Increase of Reported Cervical Spine Injuries in Comparison to Former Studies

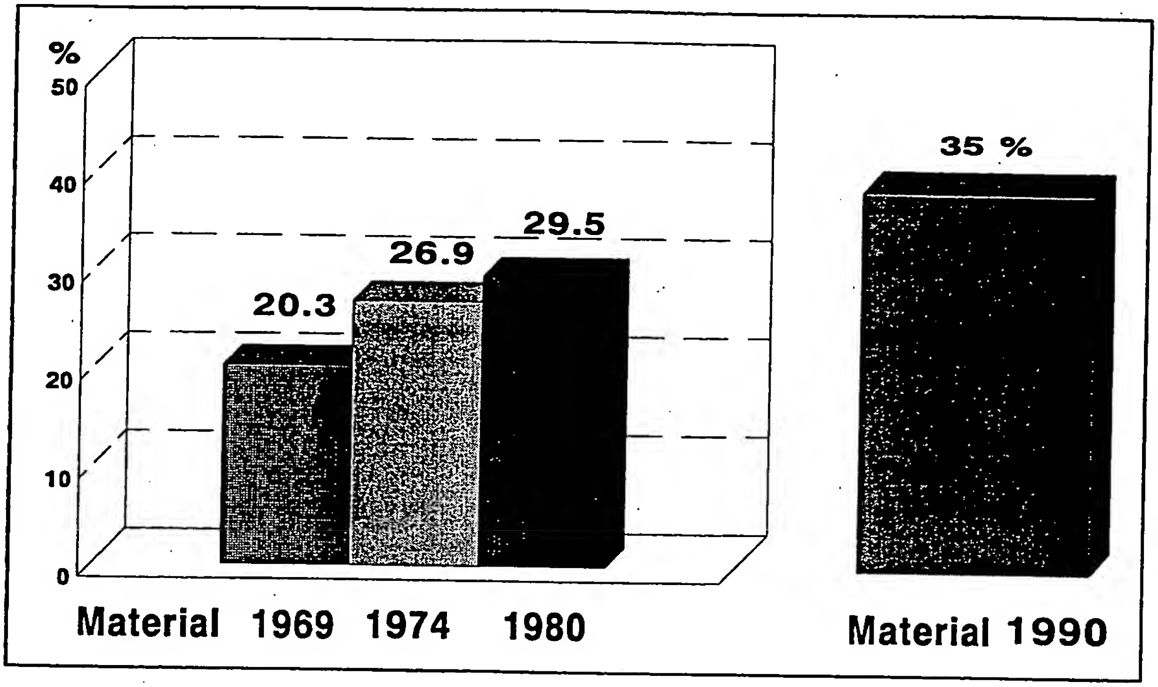

Figure 2: Frequency and Severity of Injuries of Car Passengers

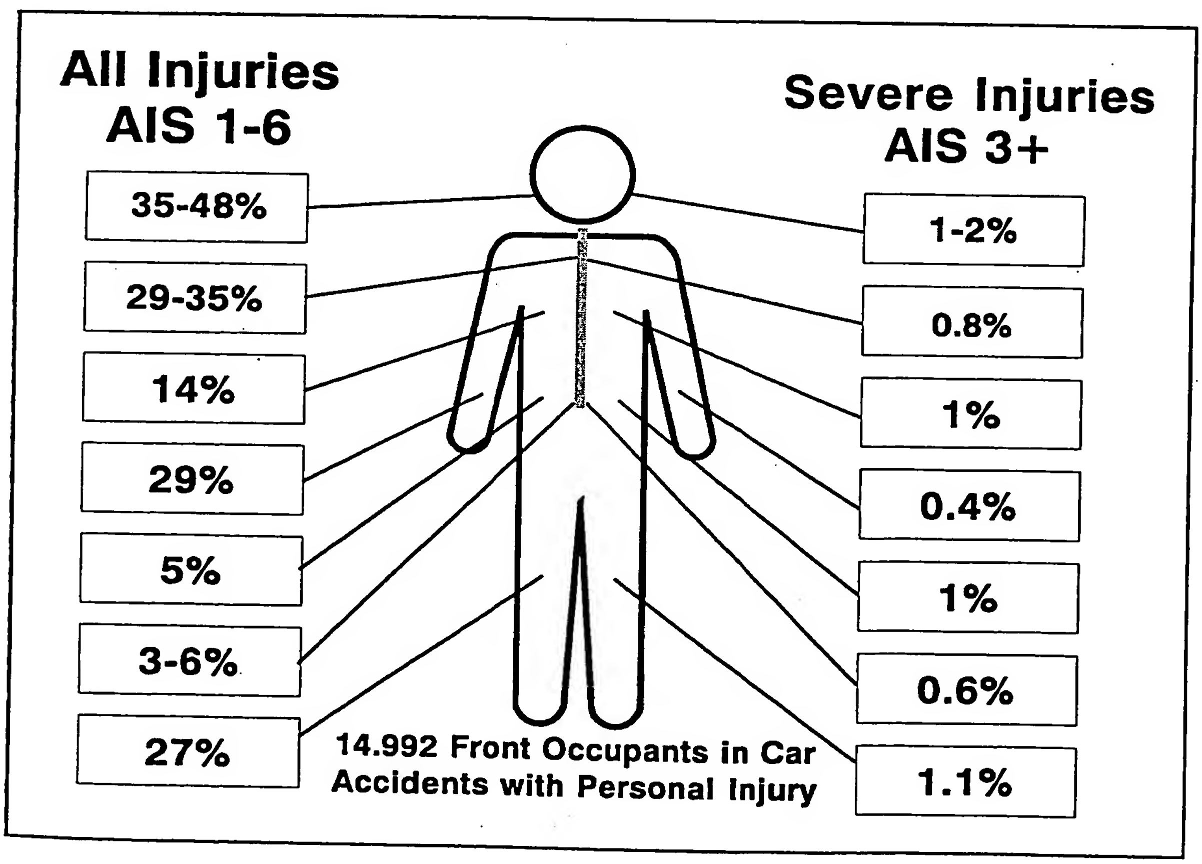

Figure 3: Examples of Insufficient Height-Adjustment/Geometry of Head-Rest

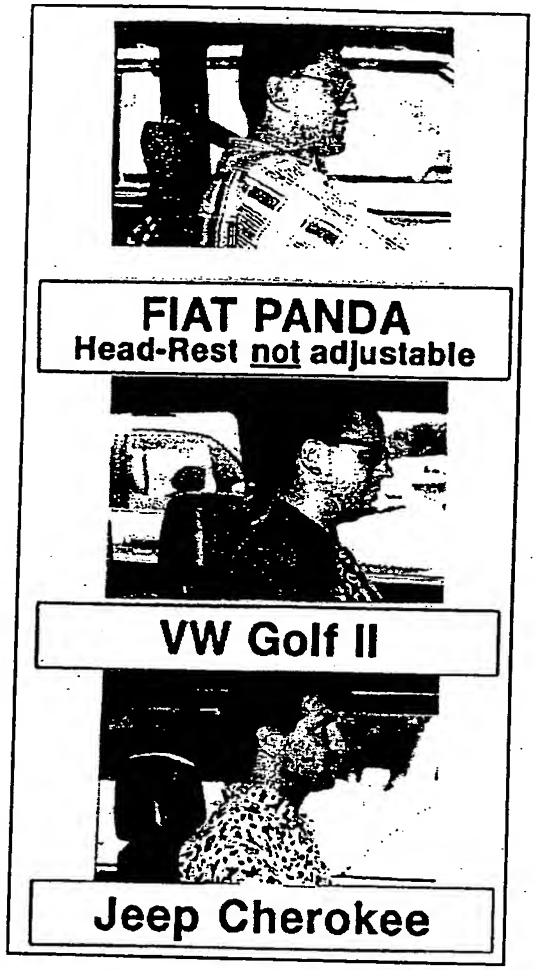

Figure 4: Head Restraint Adjustment

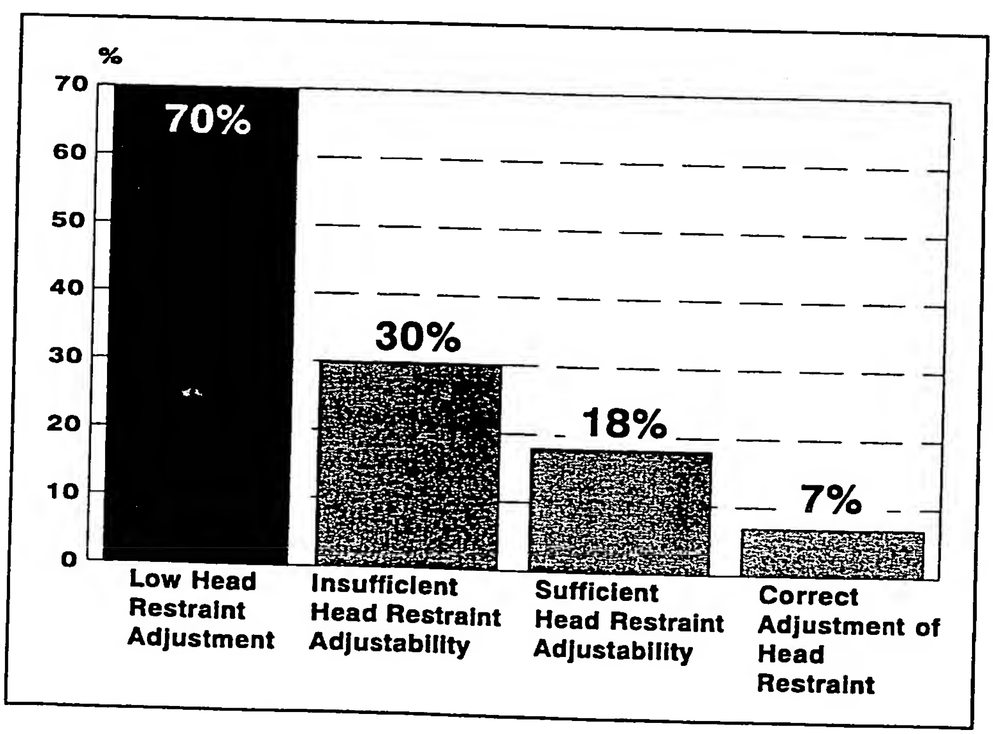

Figure 5: Case Example - Reported Solitary Cervical Spine Distorsion with Expected Job Inability

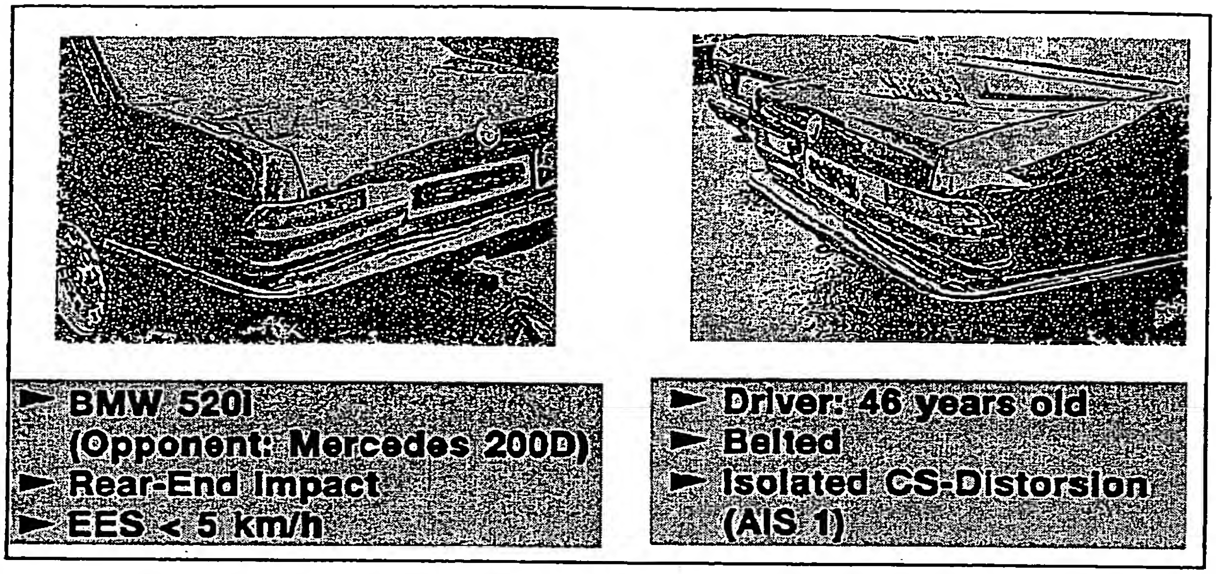

Figure 6: Case Example - No Injury - High Damage Degree

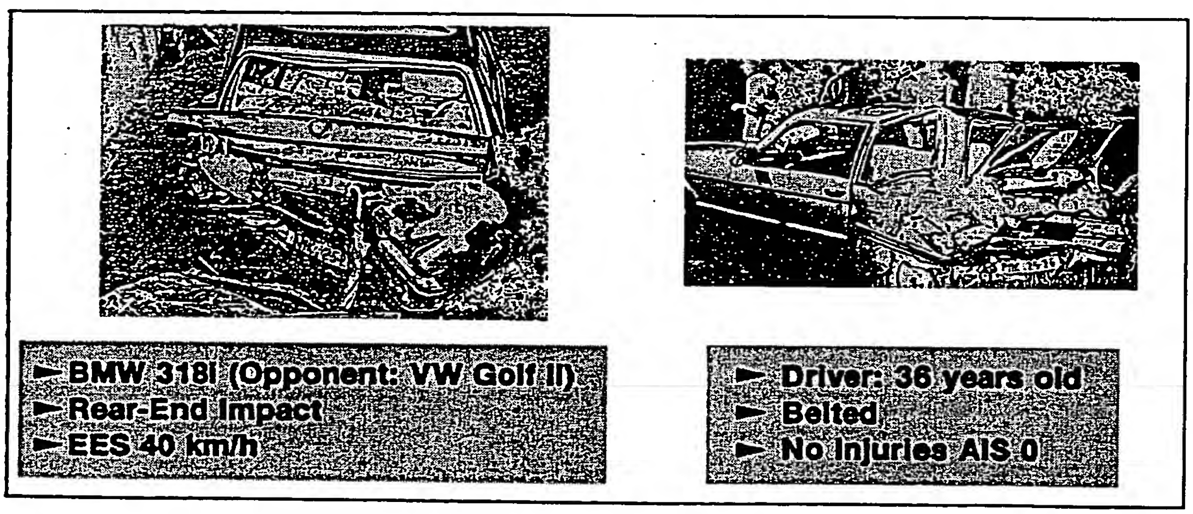

Figure 7: Symptoms

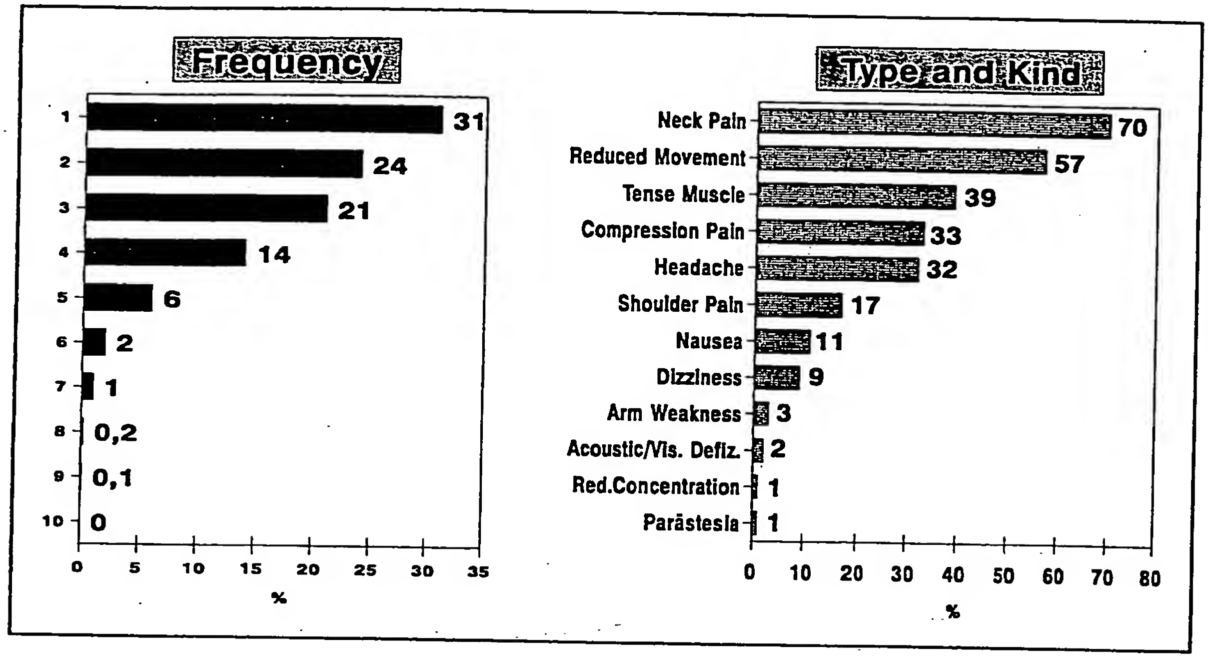

Figure 8: Δv and Reported Cervical Spine Injury

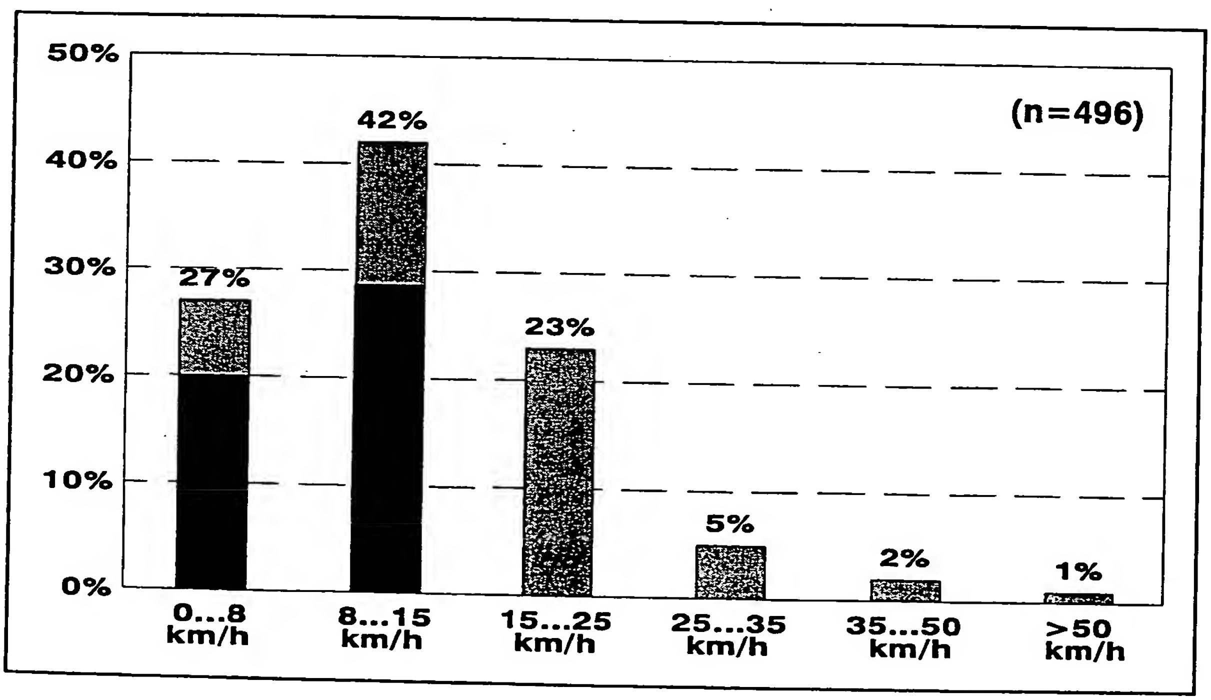

Figure 9: Neck Injury Factor (NIF) and Car Mass

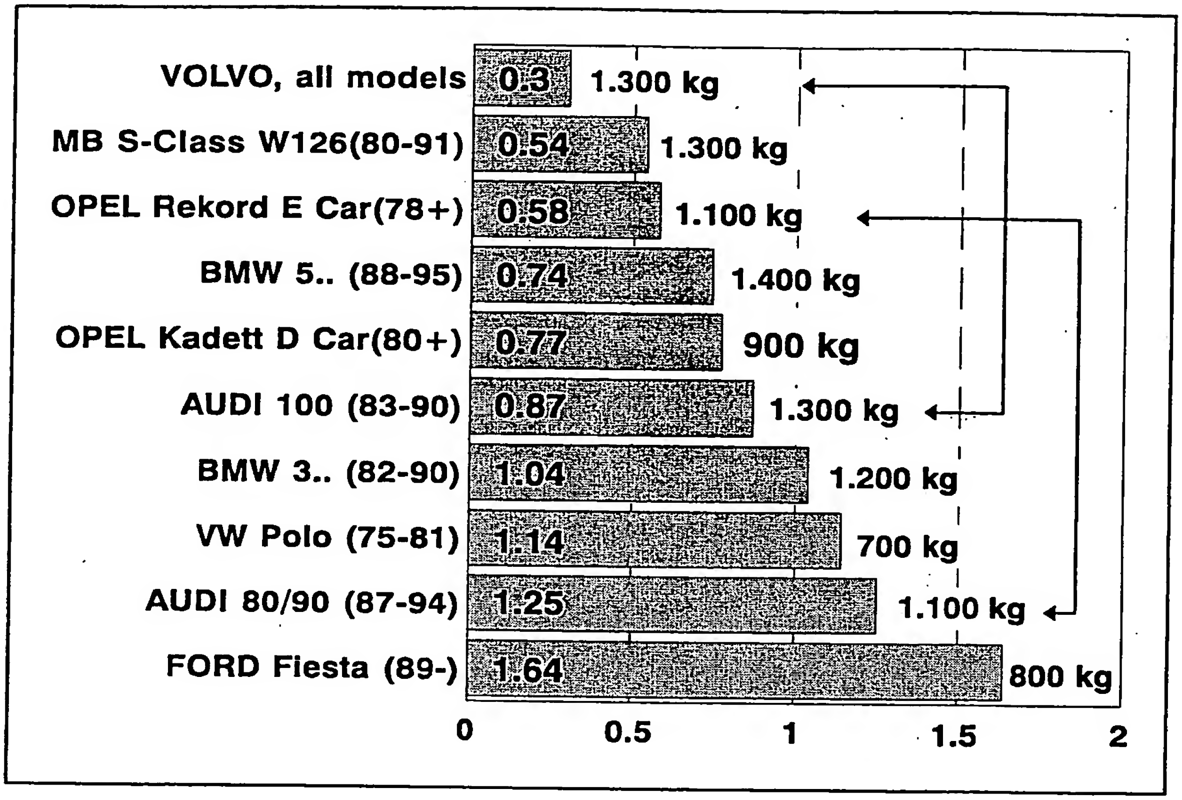

Figure 10: Relative Risk of a Cervical Spine Distorsion after a Rear End Crash

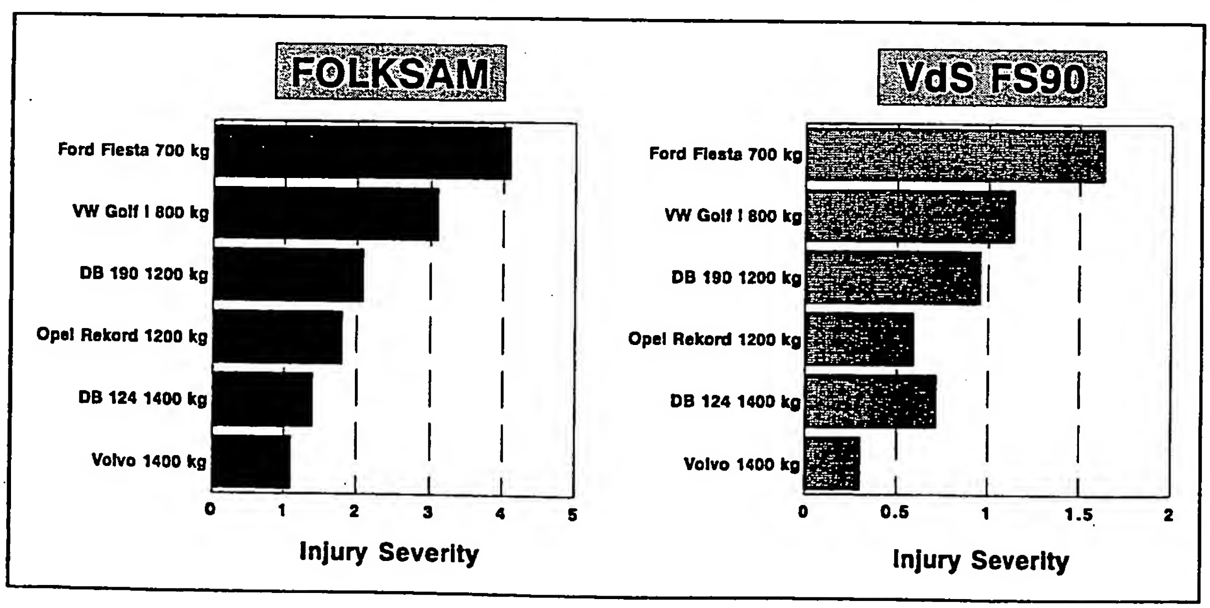

Figure 11: Sled Tests with Volunteers in Cooperation VdS Munich/TU Graz

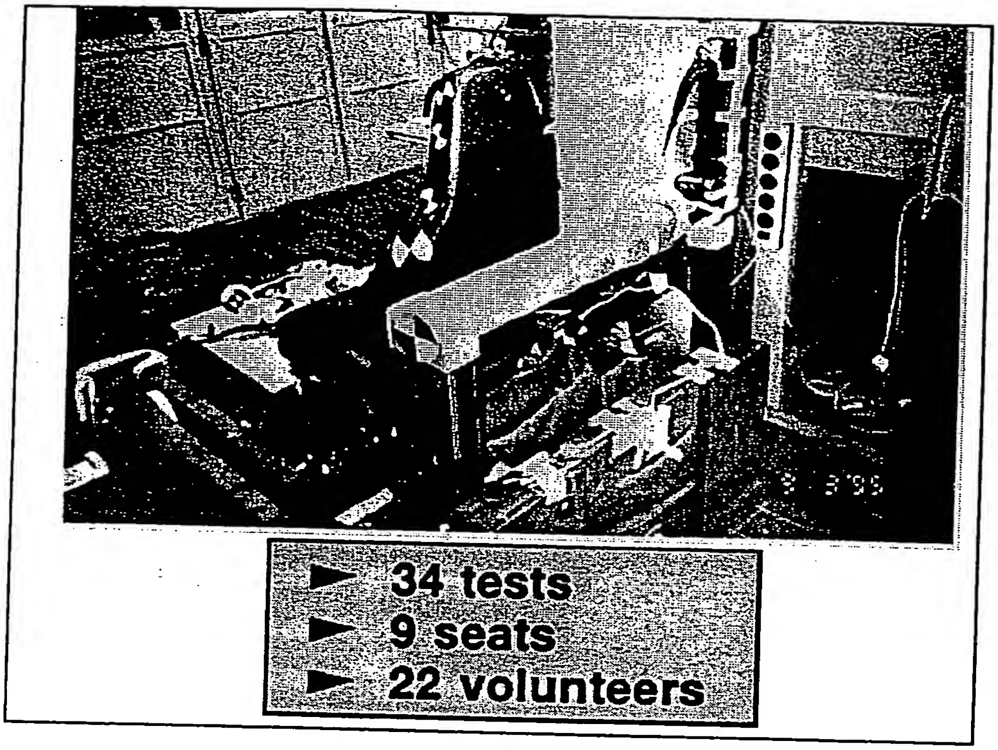

Figure 12: Sled Test - Rear Impact $\Delta v = 8.5$ km/h

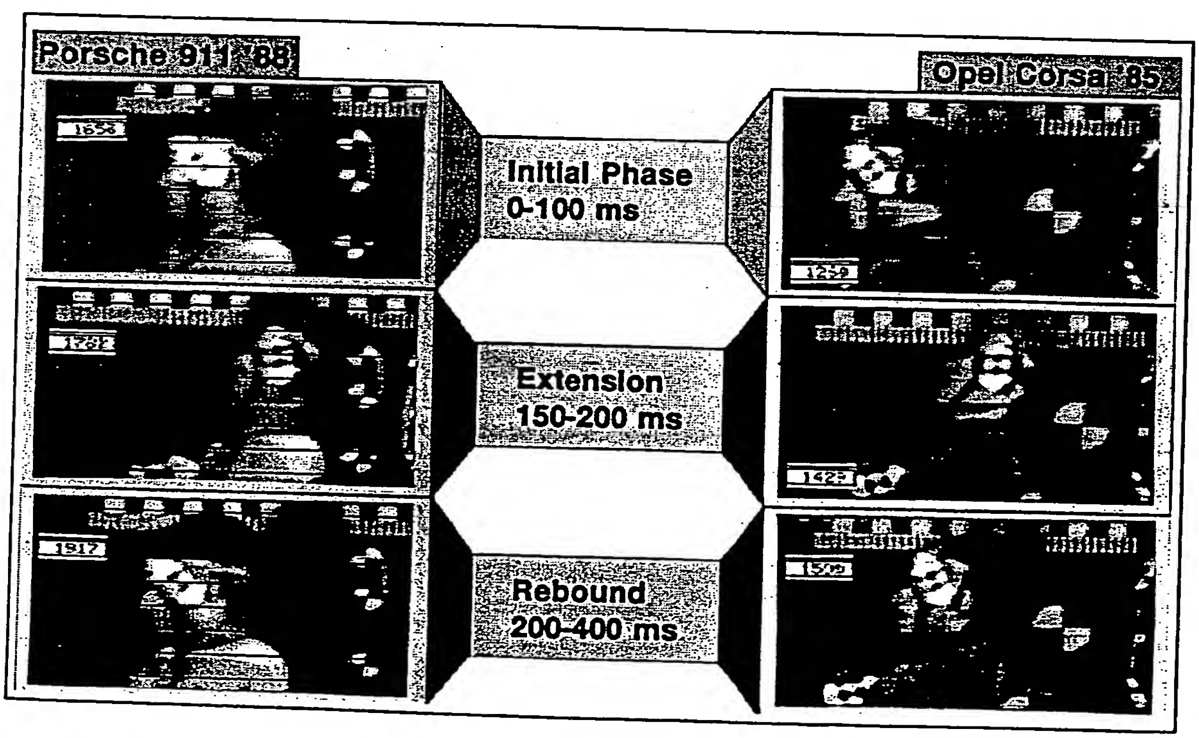

Figure 13: Correlation between Horizontal Distance and Angular Displacement

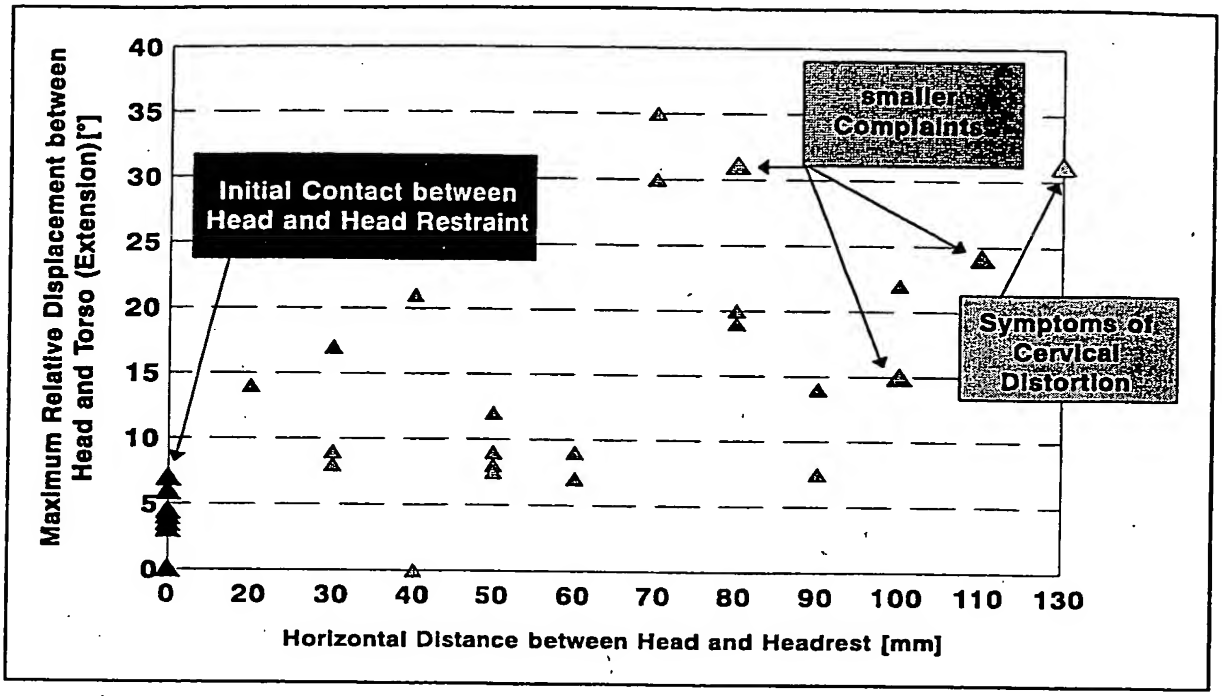

Figure 14: Evaluation of current Headrests by Geometrical Measurement with H-Point Dummy

Pos.	Car Model '95	Rating	
1	Volvo 850	1.42	Good
8	Fiat Punto Cabrio	2.25	
14	Opel Astra	2.54	Marginal
26	Lancia Y	2.75	
41	Fiat Punto	2.92	
48	Fiat Coupé	3.04	
67	Audi A4	3.33	
75	Alfa Romeo 164	3.50	Poor
83	Lancia Delta	3.58	
84	BMW 3series	3.67	
101	VW Golf III	4.00	

Source: "Stern" 23/96